LBNE Reconfiguration: Details on Sensitivities

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For the LBNE LBL Physics Working Group
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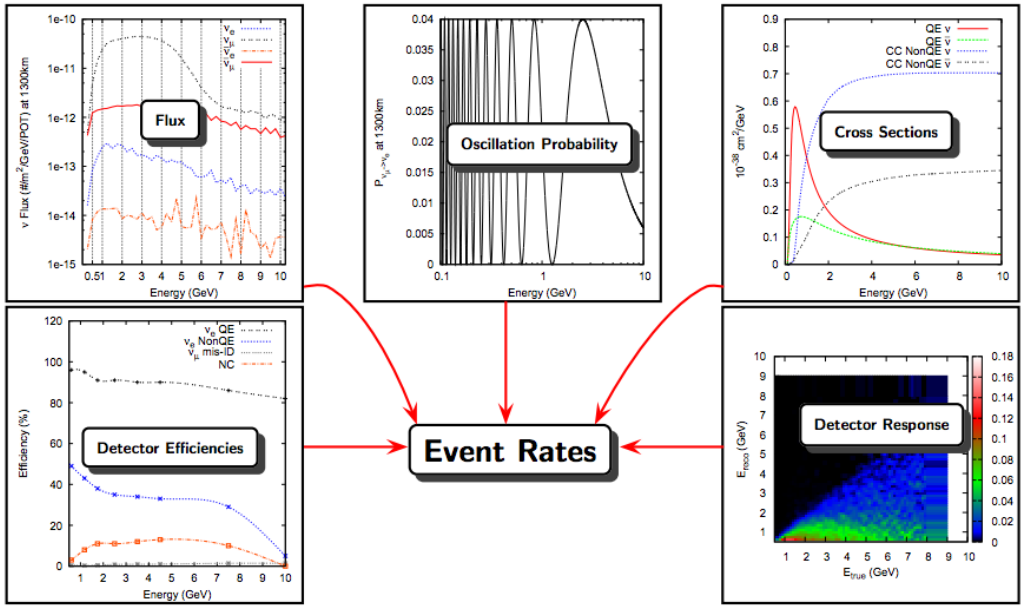
Overview

- The purpose of this talk is to provide additional details on sensitivity studies done by the LBNE Long Baseline Physics Working Group
- Inputs to GLoBES studies
  - Beams
  - Neutrino oscillation parameters
  - Assumed detector characteristics
- Sensitivity Studies
  - Methods for extracting sensitivities
  - Sensitivities for realistic options
    - Some overlap with Mary's talk
    - Focus on LBNE 5kT, LBNE 10kT, Soudan 17kT
    - Single experiment only – no combination with T2K & NOvA
- Summary

GLoBES Introduction

- Calculates oscillation probabilities
- Flux, cross-sections, and detector efficiency/response provided via external inputs
- Event Rate =
  (Flux) × (Cross Section)
  × (Detector Efficiency)
  × (Oscillation Probability)
- Calculates $\Delta\chi^2$ for a given hypothesis including oscillation parameter correlations and systematics



Huber,Lindner,Winter, arXiv:hep-ph/0407333 (2005)
Huber,Kopp,Lindner,Rolinec,Winter, arXiv:hep-ph/0701187 (2007)

GLoBES Inputs: Beam

	LBNE LE	NuMI LE	NuMI ME
Used for	LBNE	Soudan	Ash River
Primary Beam	120 GeV p^+	120 GeV p^+	120 GeV p^+
POT/year	6.0×10^{20}	6.0×10^{20}	6.0×10^{20}
Target	graphite, cylindrical	graphite, rectanguloid	graphite, rectanguloid
Horn(1/2)	NuMI, 250 kA	NuMI, 185 kA	NuMI, 200 kA
Target-Horn distance	30 cm	45 cm	135 cm
Decay pipe	4 m diameter, 280 m long, evacuated	2 m diameter, 677 m long, evacuated/He	2 m diameter, 677 m long, evacuated/He

GLoBES Input: Oscillation Parameters

Parameter	Value	Relative Error	Source
θ_{12}	0.593 ± 0.018	3%	Fogli, et al.
θ_{13}	0.154 ± 0.005	3%	Daya Bay (syst)
θ_{23}	0.705 ± 0.708	11%	Fogli, et al.
Δm^2_{21}	$(7.58 \pm 0.23) \times 10^{-5}\ eV^2$	3%	Fogli, et al.
Δm^2_{31}	$(2.35 \pm 0.12) \times 10^{-3}\ eV^2$	5%	Fogli, et al.

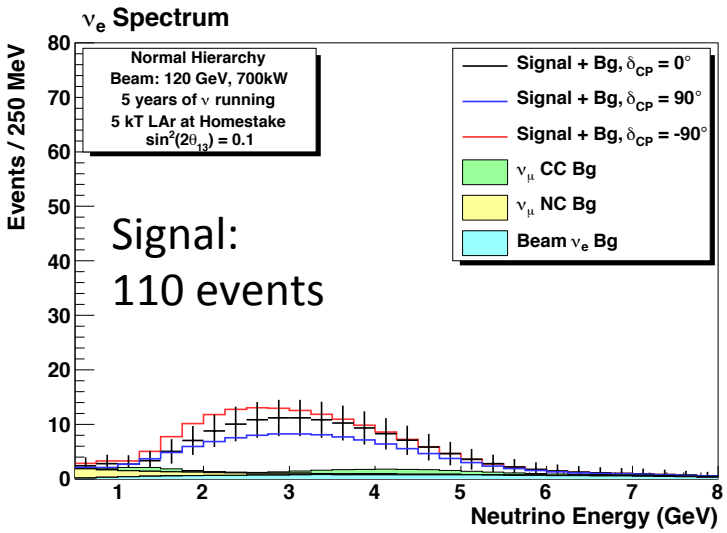
- Fogli, et al: arXiv:1106.6028v2 (2011)
- Daya Bay: arXiv:1203.1669v2 (2012)

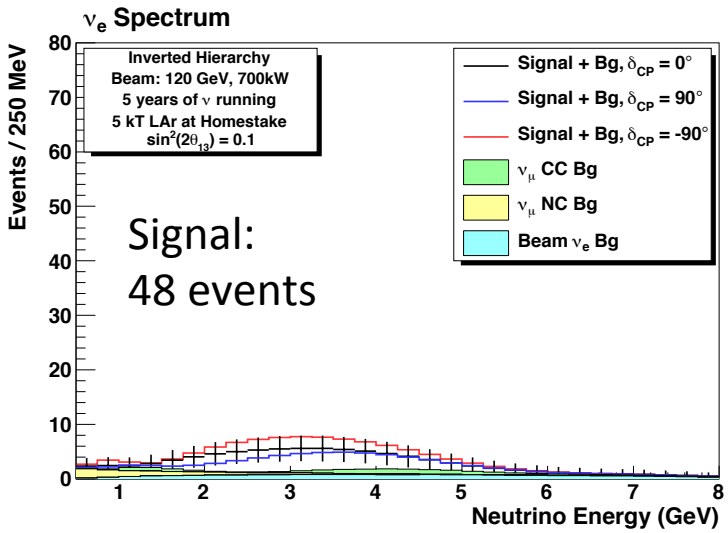
*Include disappearance mode: if our data constrains a parameter better than these values, that constraint is used.

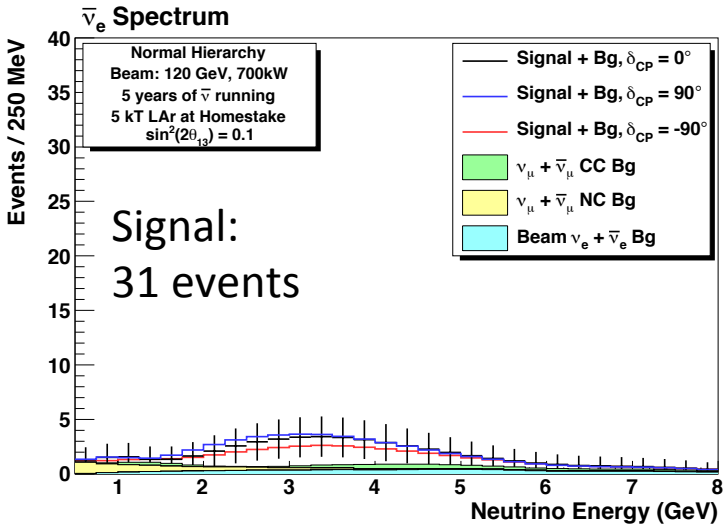
GLoBES Input: Detector Characteristics

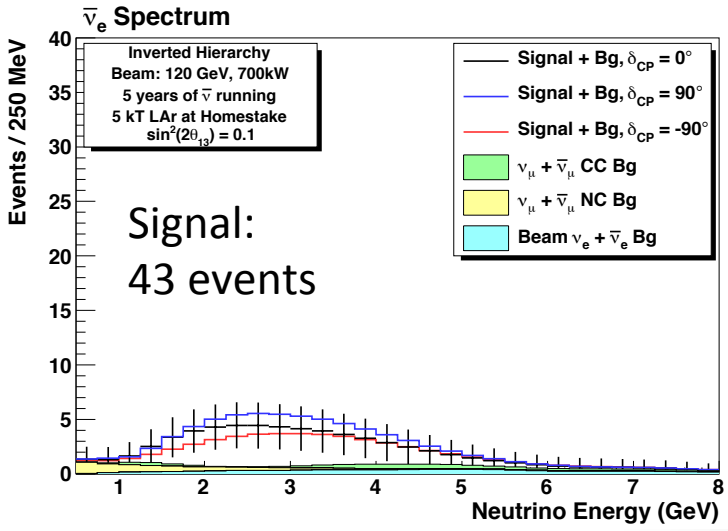
- Focus on ν_e appearance
- Signal
  - 80% efficiency
  - 15%/√E resolution
  - 1% normalization uncertainty
- Background
  - ν_μ NC: 1% efficiency, WC smearing
  - ν_μ CC: 1% efficiency, 15%/√E resolution
  - ν_e intrinsic beam CC, 80% efficiency, 15%/√E resolution
  - 5% normalization uncertainty on sum of backgrounds

ν_e Appearance Spectra: LBNE 5 kT

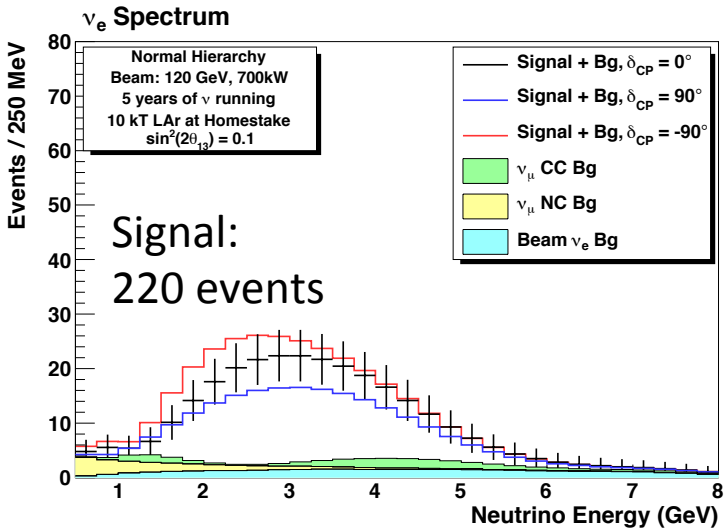


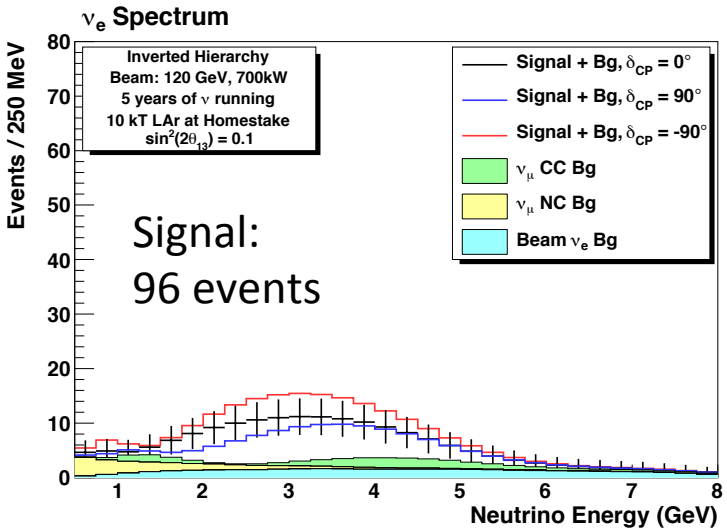


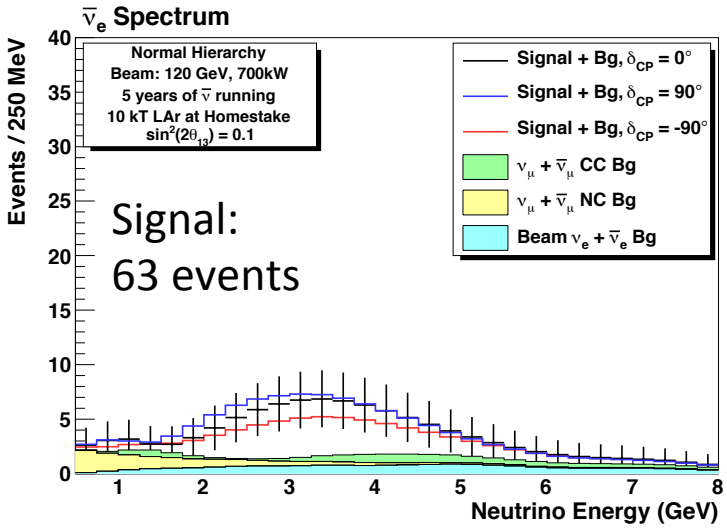


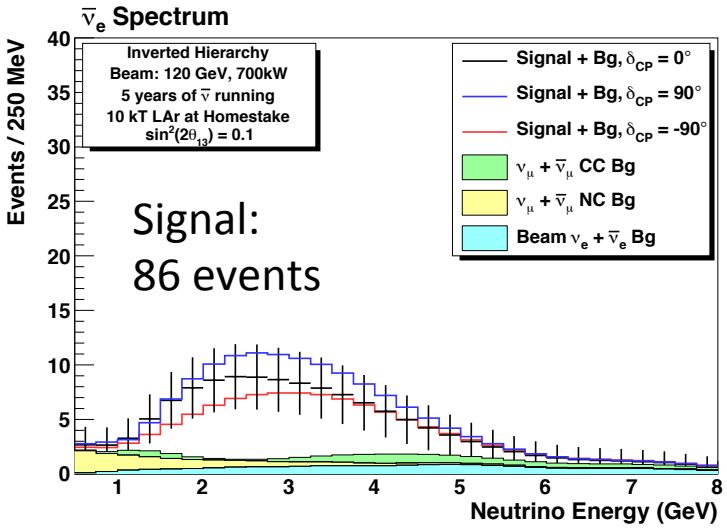


ν_e Appearance Spectra: LBNE 10 kT

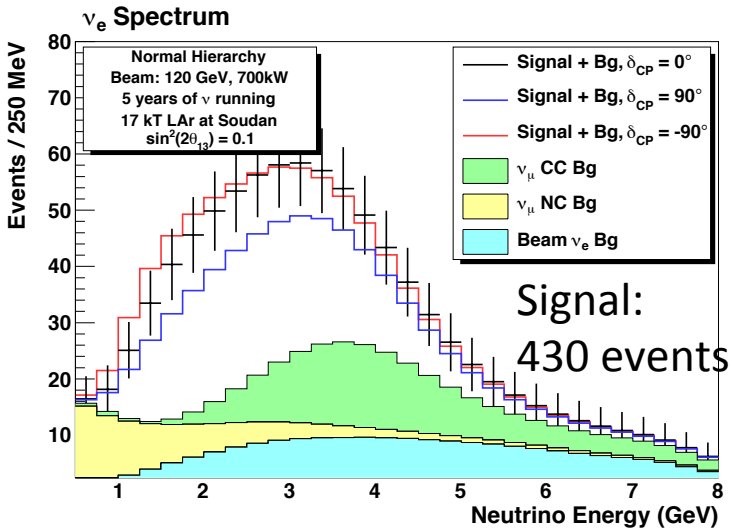


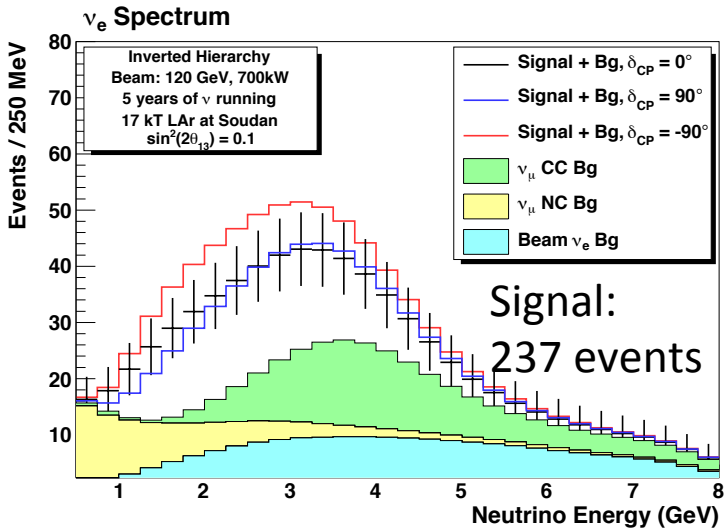


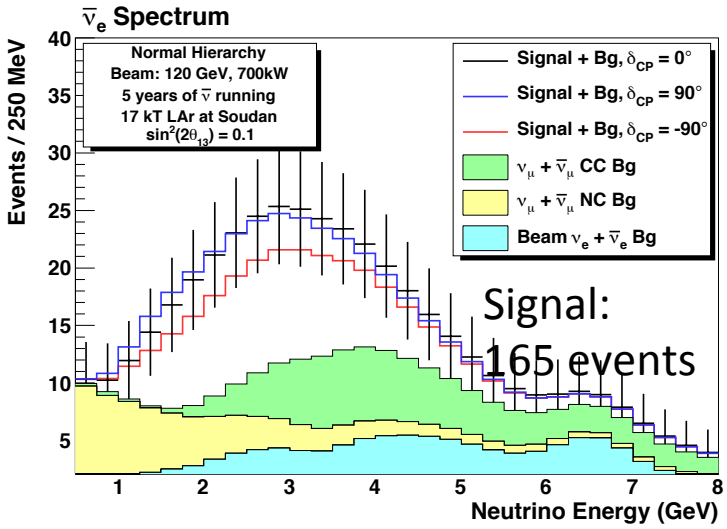


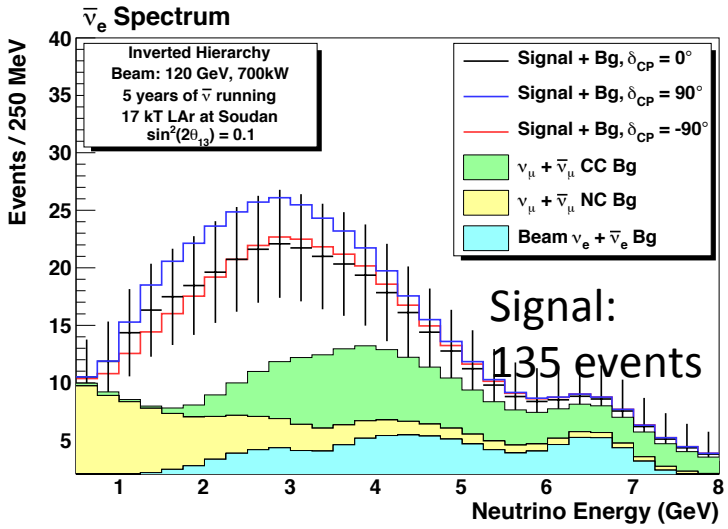


ν_e Appearance Spectra: Soudan 17 kT



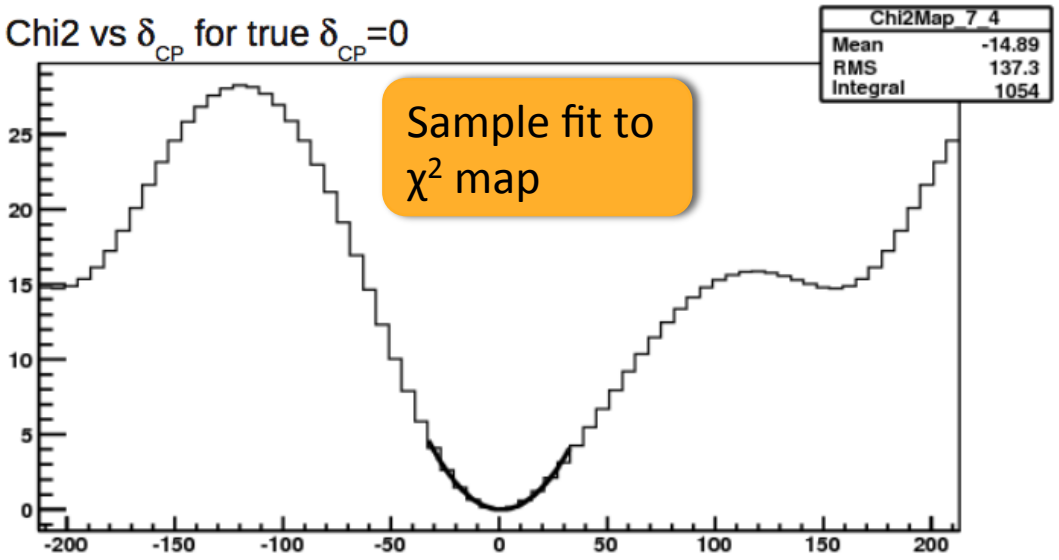




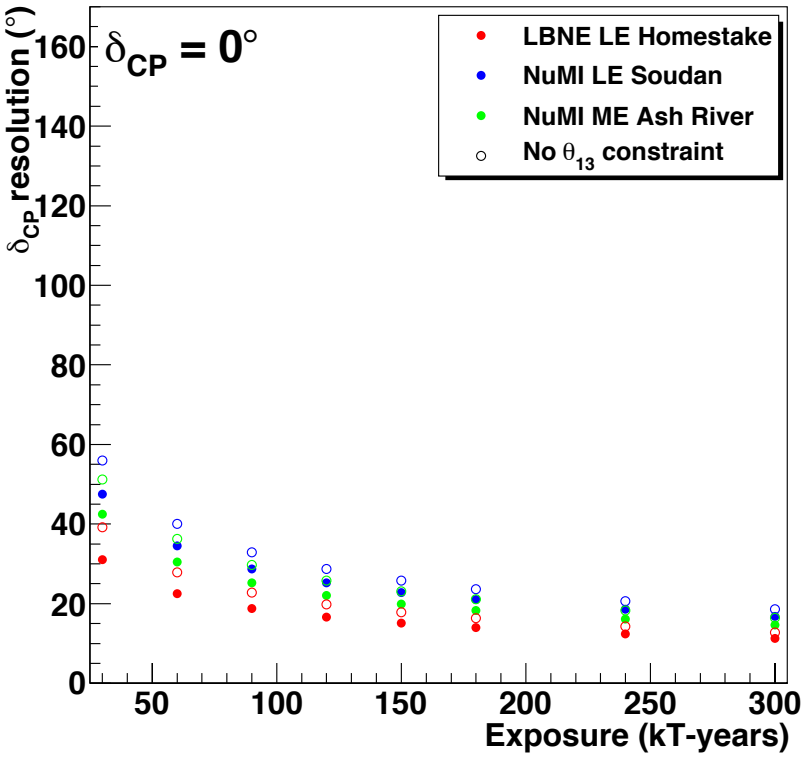


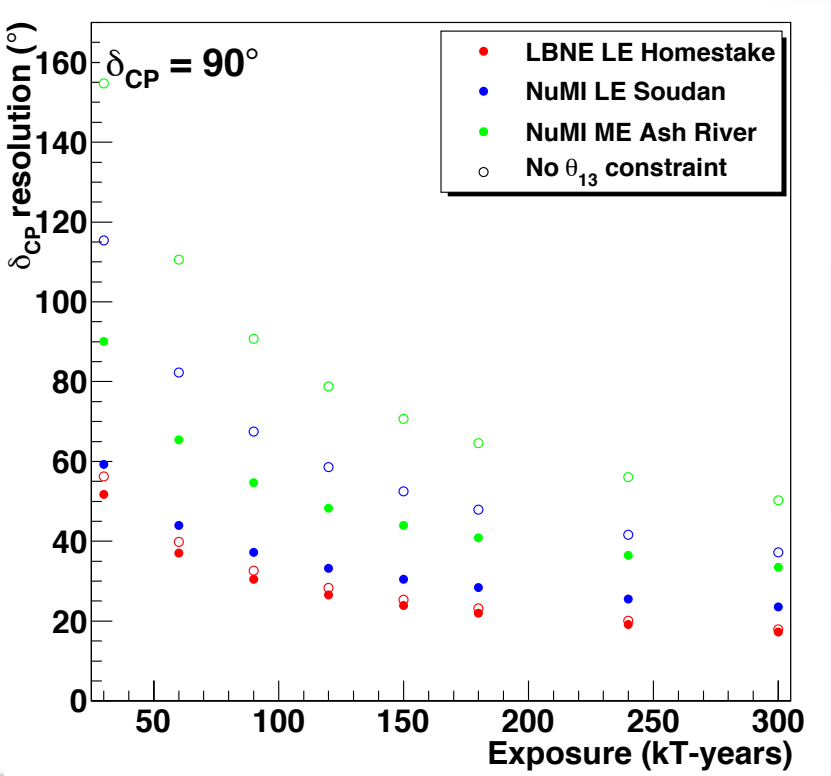
δ_{CP} and θ_{13} Resolution Calculation

- χ^2 comparing the "true" spectra for δ_{CP} or θ_{13} and the "test" spectra for a range of values around $\delta_{CP,true}$ or $\theta_{13,true}$ is computed
- Fit range of values around minimum of 1-D χ^2 map with 2nd degree polynomial function
- Calculate 1σ resolution using parameters of fit function



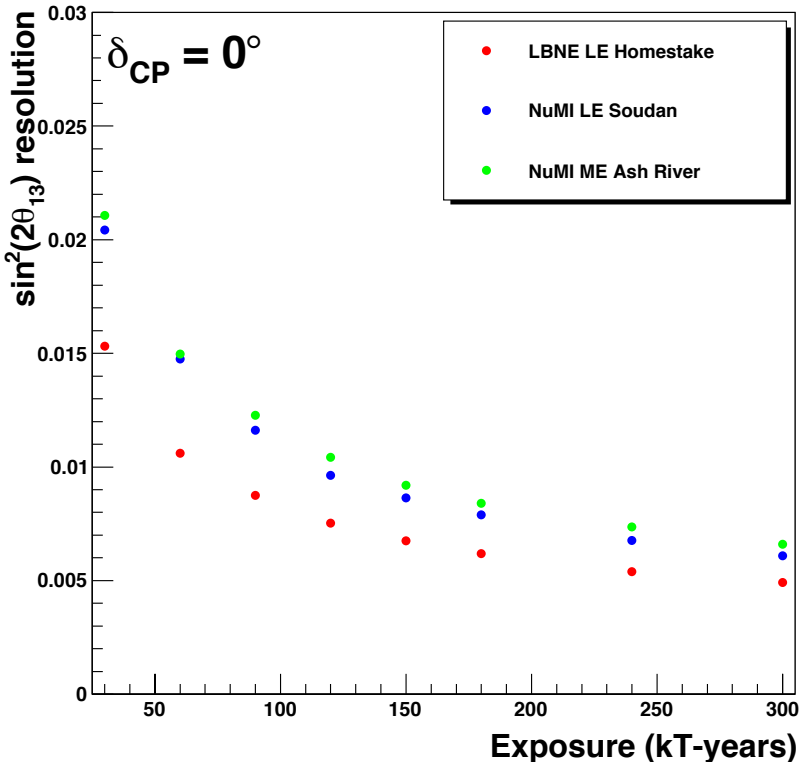
δ_{CP} Resolution

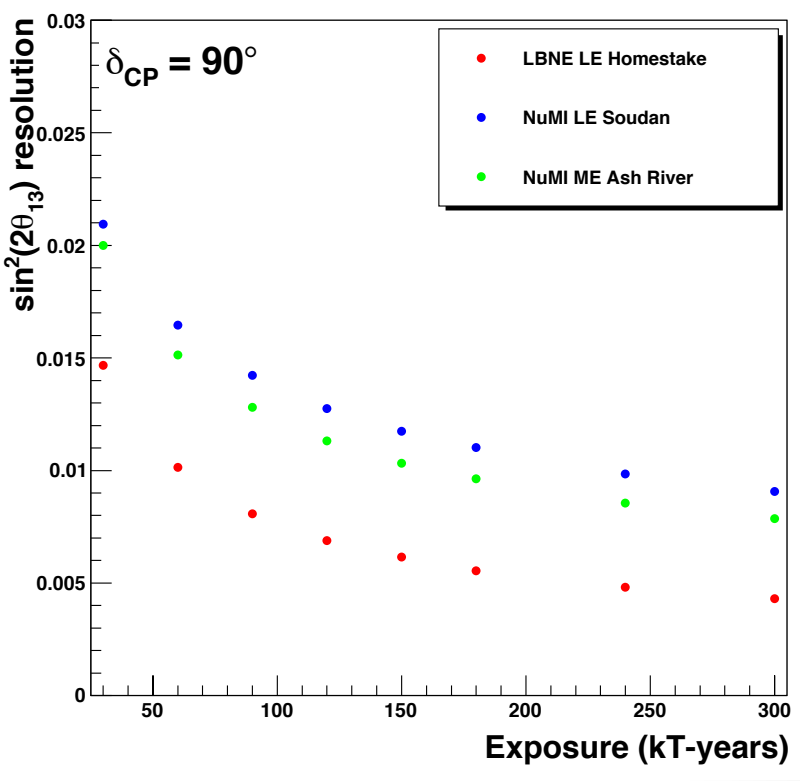




With external θ_{13} constraint:
LBNE 5 kT: δ_{CP} resolution ~25° for δ_{CP} = 0°; ~40° for δ_{CP} = 90°
LBNE 10 kT: δ_{CP} resolution ~20° for δ_{CP} = 0°; ~30° for δ_{CP} = 90°
Soudan 17 kT: δ_{CP} resolution ~25° for δ_{CP} = 0°; ~30° for δ_{CP} = 90°

θ_{13} Resolution



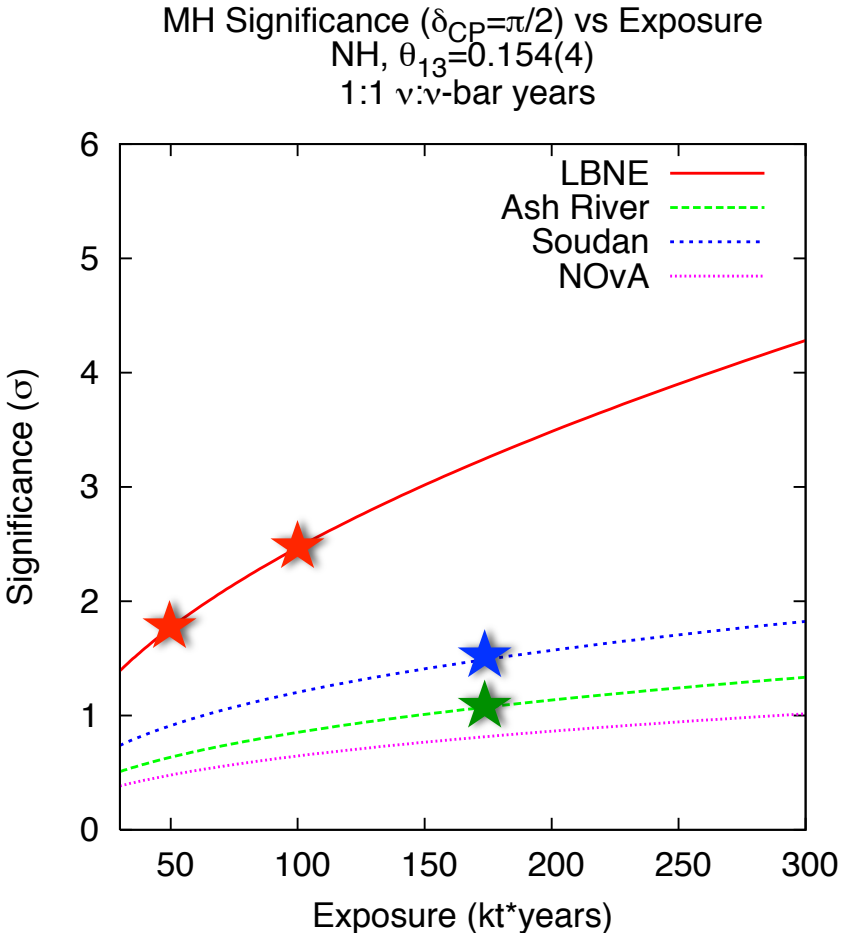


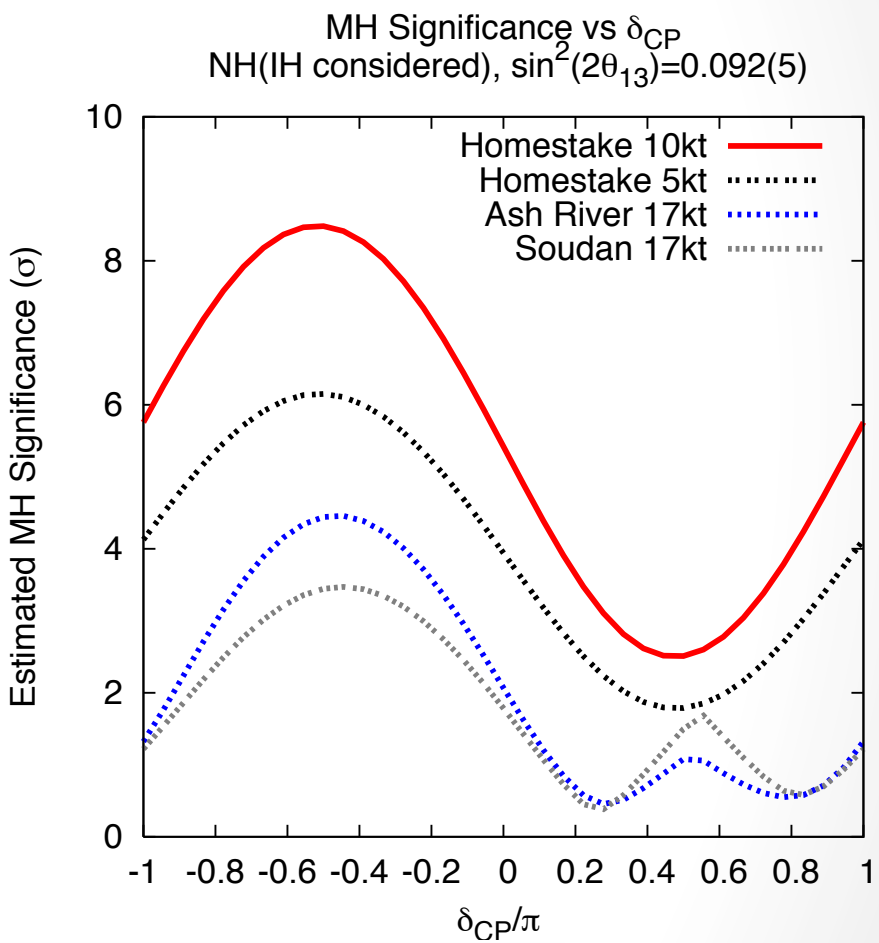
LBNE 5 kT: $\sin^2(2\theta_{13})$ resolution ~0.012 for $\delta_{CP} = 0°$; ~0.012 for $\delta_{CP} = 90°$
LBNE 10 kT: $\sin^2(2\theta_{13})$ resolution ~0.008 for $\delta_{CP} = 0°$; ~0.008 for $\delta_{CP} = 90°$
Soudan 17 kT: $\sin^2(2\theta_{13})$ resolution ~0.008 for $\delta_{CP} = 0°$; ~0.012 for $\delta_{CP} = 90°$

Mass Hierarchy Sensitivity Calculation

- χ^2 comparing the "true" spectra for $\Delta m^2_{31} > 0$ and the "test" spectra for $\Delta m^2_{31} < 0$ is computed
- First, minimize χ^2 allowing oscillation parameters for the test spectra to float constrained by input uncertainties
- Second, minimize χ^2 allowing the signal and background for the test spectra to float within their normalization errors
- Neutrino and anti-neutrino running treated separately
- Resulting significance is $\sigma = \sqrt{\chi^2_\nu + \chi^2_{\bar{\nu}}}$

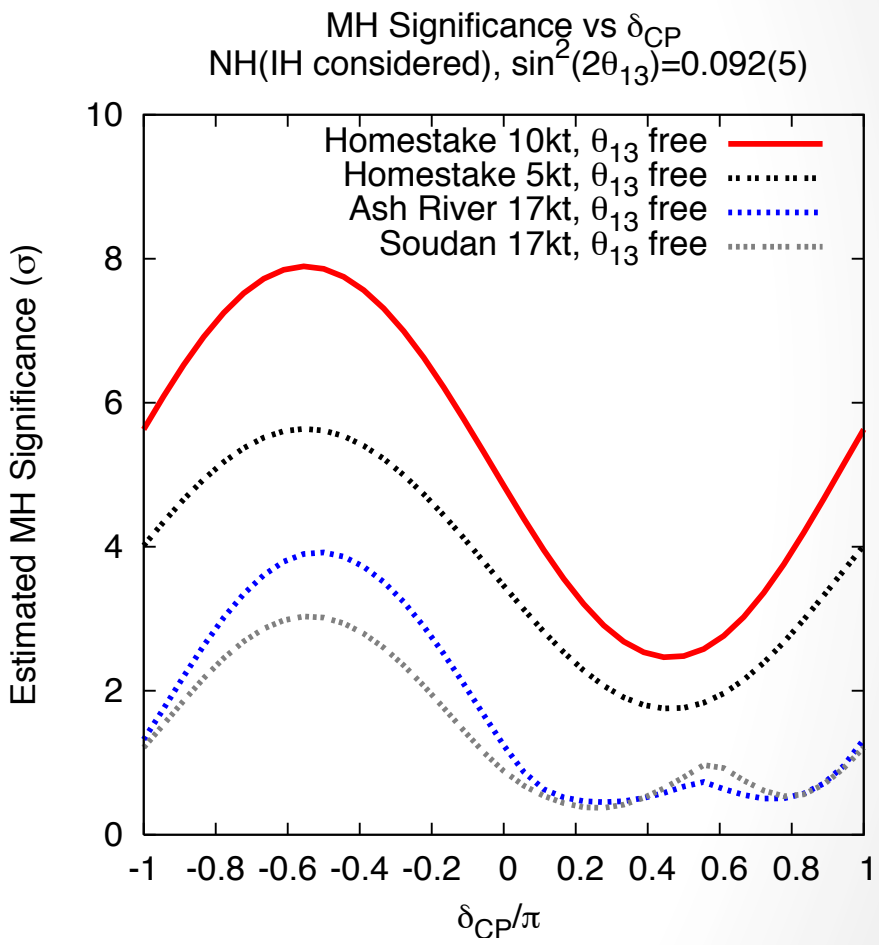
Mass Hierarchy Sensitivity





LBNE 10 kT: >2.5σ MH significance for all values of δ_{CP}
LBNE 5 kT: >2σ MH significance for most values of δ_{CP}
Soudan 17 kT: 2-4σ MH significance for negative values of δ_{CP}

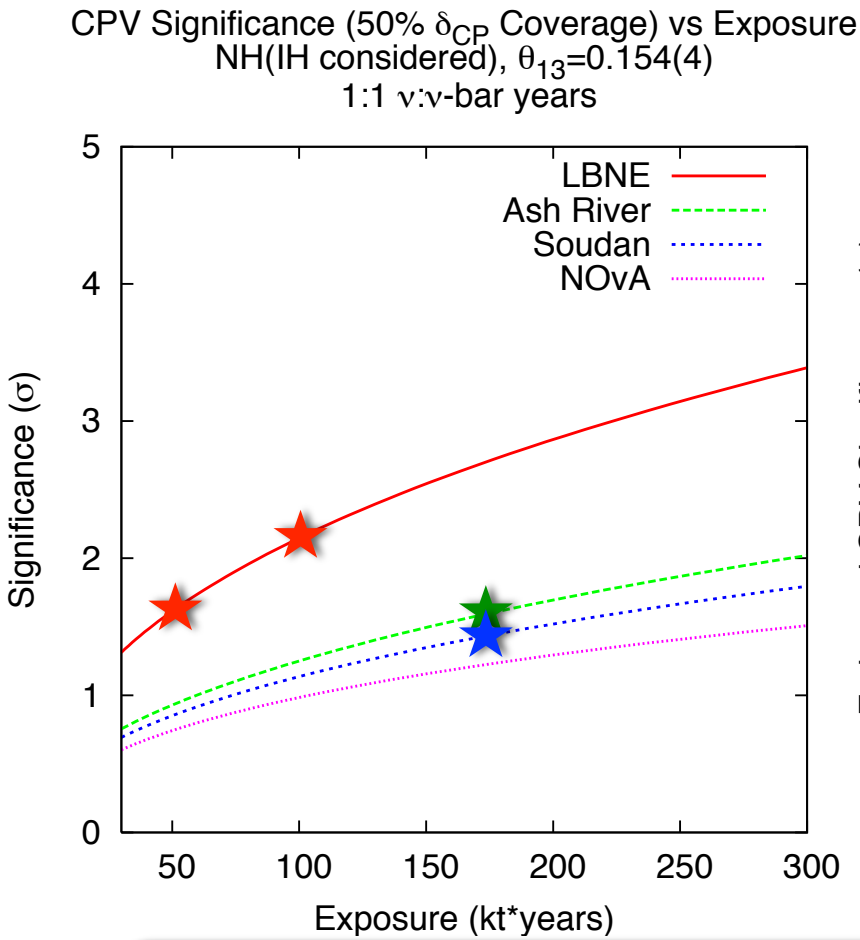
Mass Hierarchy Sensitivity: No θ_{13} constraint

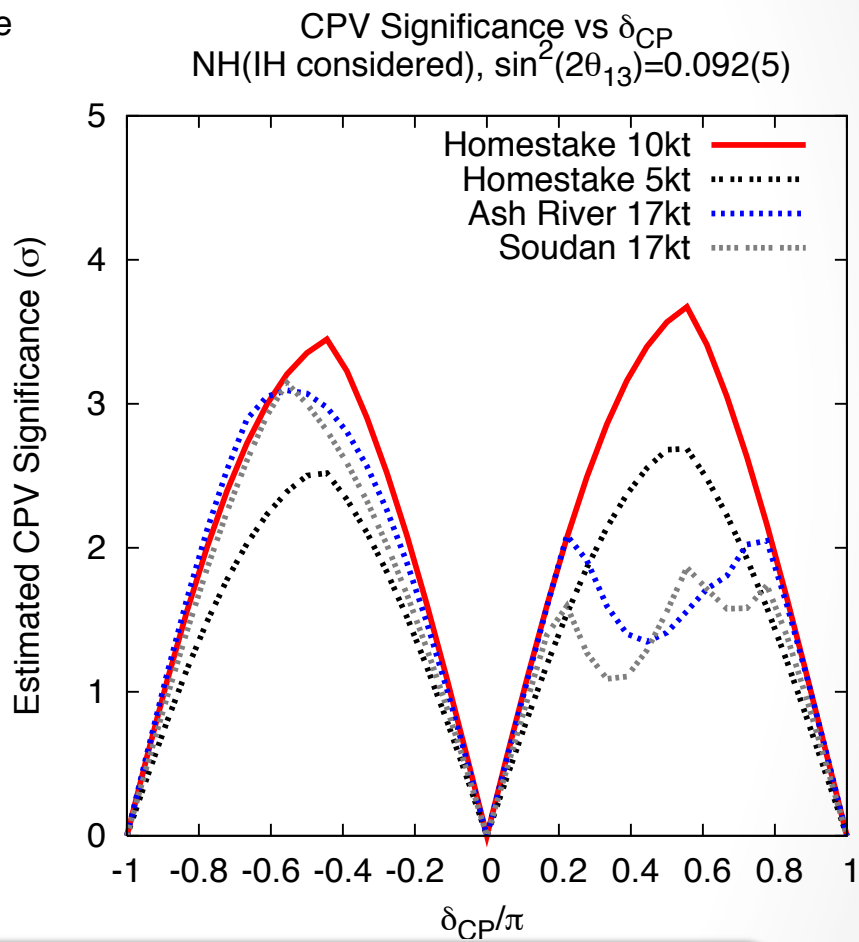


CP Violation Sensitivity Calculation

- χ^2 comparing the "true" spectra for $\delta_{CP} = 0,\pi$ and the "test" spectra for a range of 100 $\delta_{CP,test}$ values from $-\pi$ to π is computed
- First, minimize χ^2 allowing oscillation parameters for the test spectra to float constrained by input uncertainties, but keeping $\delta_{CP,test}$ fixed
- Second, minimize χ^2 allowing the signal and background for the test spectra to float within their normalization errors
- Parallel minimization for both values of $\delta_{CP,true}$ and both mass hierarchies – keep minimum of these χ^2 values
- Sort 100 χ^2 values in descending order – CPV sensitivity for 50% of δ_{CP} values is calculated from 50th χ^2 value on list
- Neutrino and anti-neutrino running treated separately
- Resulting significance is $\sigma = \sqrt{\chi^2_\nu + \chi^2_{\bar{\nu}}}$

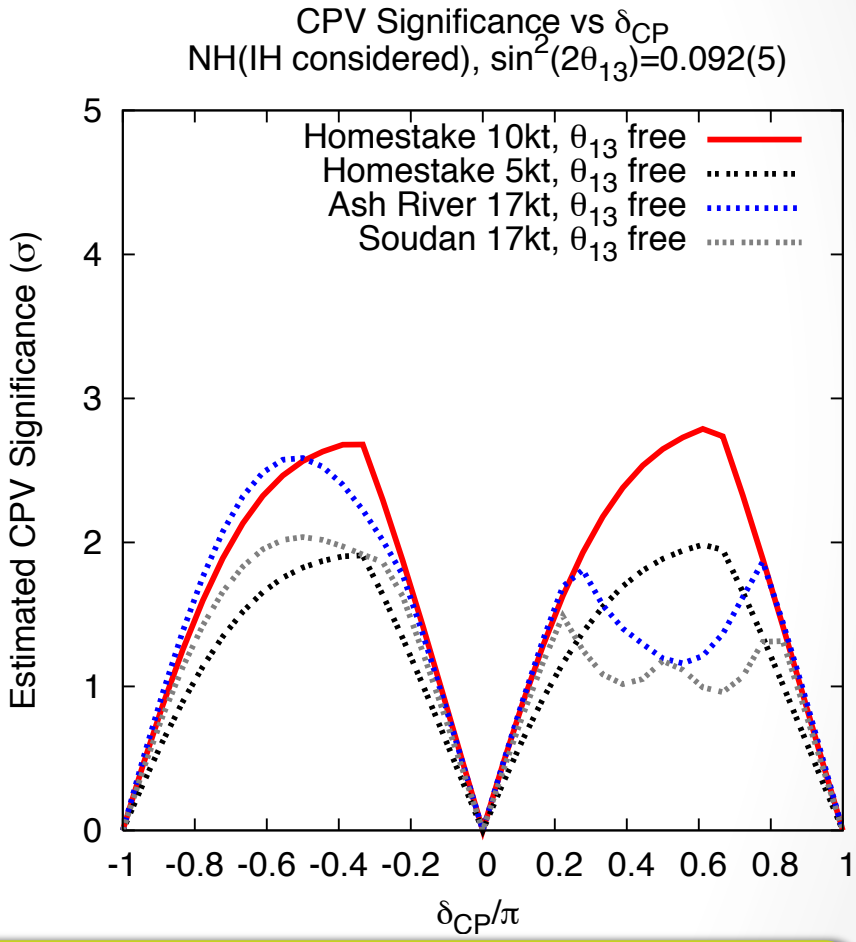
CP Violation Sensitivity





With external θ_{13} constraint:
LBNE 10 kT only option providing >2σ CPV significance for 50% of δ_{CP} values
>3σ CPV significance possible only for small range of δ_{CP} values

CP Violation Sensitivity: No θ_{13} constraint



Without external constraint on θ_{13}:
No option provides >3σ CPV significance
LBNE 10 kT only option providing >2σ CPV significance for large fraction of δ_{CP} values

Summary

- ν_e appearance event totals
  - LBNE 5 kT sample size is small with very low background
  - LBNE 10 kT sample size is moderate with very low background
  - Soudan 17 kT sample size is bigger with large background
- LBNE 10 kT is significantly better than LBNE 5 kT for resolutions and sensitivities
- LBNE baseline/beam provides sensitivity to MH and CPV for a larger fraction of possible δ_{CP} values than Soudan baseline/NuMI beam
- Best possible CPV significance:
  ~3.5σ for δ_{CP} near $\pm\pi/2$ with LBNE 10 kT and external constraint on θ_{13}